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Structural Evaluation of Aircraft Stiffened Panel

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Abstract: ***A structure has to be designed to ensure the safety throughout the service life. To ensure this, the designer should first understand how the structure behaves with respect to the material, sectional and loading conditions. In the modern aircraft structural design, the high accuracy design to obtain the highest efficiency of the structure is possible through the consideration of selective design properties in particular to perform the analysis. Stiffener or longeron or stringer is a thin metal strip that is used as a supporting member in fuselage and wing. When we consider the issue i.e. resistance of the aircraft's skin towards the loads applied on it, due to frailty the aircraft skin is easily deformed. In order to solve this problem we designed a stiffened panel which can endure to deflection and stress levels. By changing the stiffened panel sections and by changing the material of the skin, the aircraft skin can withstand the deformation. In current study a representative stiffened panel from a transport aircraft is considered for the evaluation. The structural analysis of the stiffened panel will be carried out with the different cross-sections of the stiffeners with the varying material types. Von-misses stress and the deformation is determined with the varied cross-sections with change of materials to determine the better section for the development of the aircraft structural strength. The study includes material properties to sustain the loads induced with the cross-sectional behavior of the stiffened panels. This paper evaluates the robust material to use and to find out the best capable section for the Stiffened panel.***

Keywords: Stiffened Panel, Design, Cross-sections, Material, Structural Analysis

1. Introduction

1.1 Introduction to the Stiffened Panels

The stiffened panel is the elementary part of most of the airframe structures with intermediate and higher loading intensity. Stiffened panel is composed of two basic structural parts: Longitudinal reinforcing members (stringers) and the skin. Stiffened panels with attached Stiffener Sections are widely used in the aerospace and other prominent engineering structures when the structural weight of a material and the strength is an most important concern.

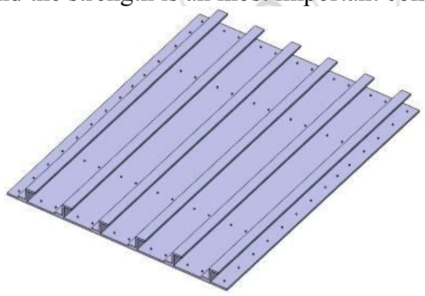

Figure 1.1: Stiffened Panel

The stiffened panels are the basic structural elements of most of thin wall structures especially aircraft since second half of twentieth century shown in the figure 1.1. This form of the structure is a logical development of the necessity of providing a continuous surface for an airplane, combined with the requirement of the total structure weight. This is also the main reason for stiffened panels are still the most used form of the airplane structure even for the design of modern aircraft with intermediate and higher loading intensity. Although utilization of the stiffened panel for the airplane structure is known for a relatively long time it is still very difficult to do precise prediction of the stiffened panel behavior during the loading. Despite the aircraft structure is prone to different kinds of forces; the predominant force is Static Loading. For thin walls structures (stiffened panels) the most complications are connected with buckling and post-buckling behavior during the compression.

Utilization of the stiffened panels for airframe structures is so far that even small weight reduction of each of them can significantly affect the total empty weight of the structure. On the other side, an inappropriate design of the stiffened panels can absolutely uselessly increase the total structure weight. And just here is the space for the analysis using the different sections for the stiffened panels. Placing of the stiffener on the rectangular plate is shown in the figure1.2.

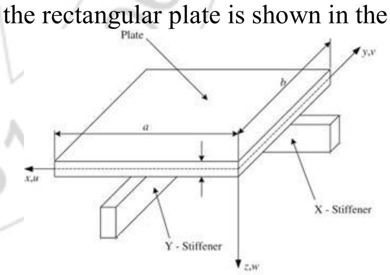

Figure 1.2: Rectangular Stiffeners Placed Along Rectangular Plate

Since the early dawn of civilization, the strong and light material has always fascinated mankind for typical applications of stiffened panels. The idea of composite materials are formed by the combination of two or more materials that retain their respective characteristics when combined together to achieve desired properties (physical, chemical, etc.) that are superior to those of individual constituents. The main components of composites are reinforcing agents and matrix. The fibers, particulates & whiskers act as the reinforcement and provide most of the stiffness & strength. The matrix binds the reinforcement together thus effecting the load transfer from matrix to reinforcement. Composites are light weight possess high strength-to-weight ratio and high stiffness-to-weight ratio as compared to conventional materials. Composite stiffened panels, which are anisotropic and orthotropic in nature, are gaining popularity in structural applications. Composite stiffened panels are generic structural elements in weight sensitive structure applications. Stiffened panel consist of composite plate provided with stiffeners in the longitudinal and/or transverse direction. Composite plate stiffened by different type of stiffeners. These are broadly classified as open type and closed type or box type. Open type are torsionally week while closed type or box type are torsionally stiff.

There are some common type of stiffeners which are in use, which actually is a plate perpendicularly attached to the composite plate. A typical arrangement of this class can be found in Fig. 1.3.These panels are becoming increasingly used in structural applications because of their high specific stiffness (stiffness per unit weight)and specific strength (strength per unit weight). The stiffened elements representing a relatively small part of the total weight of the structure substantially influence their stiffness and stability.

For the further study of the paper, choosed particularly three different type of sections concentrating the behaviour with the composite material in comparison with the other commonly used materials in the aircraft design structures.

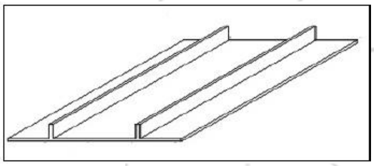

Figure 1.3: Composite blade stiffened panel(open type)

1.2 Objective

The objective of this study is to investigate the behaviour of stiffened plates subjected to in-plane loading. An experimental investigation has been performed to gather sufficient data and understanding of stiffened plates. Ansys Workbench has been used for generation of data for parametrical study. The effects of Stress and deformation are investigated on the varied material types with the change of Cross-sections of the stiffeners. The behaviour of stiffened plates and effects of various parameters are discussed.

1.3 Advantages

Stiffeners in a stiffened plate make it possible to sustain highly directional loads, and introduce multiple load paths which may provide protection against damage and crack growth under the compressive and tensile loads. The biggest advantage of the stiffeners is the increased bending stiffness of the structure with a minimum of additional material, which makes these structures highly desirable for loads and destabilizing compressive loads. In addition to the advantages already found in using them, there should be no doubt that stiffened plates designed with different techniques bring many benefits like reduction in material usage, cost, better performance, etc.

Discussing, the advantages of the stiffened panel with the application of composite material in particular due to the both features of structural and material forms. It has the tensile strength of composites is four to six times greater than that of steel or aluminium. Unidirectional fiber composites have specific modulus (ratio of material stiffness to density) about 3to 5 times greater than that of steel and aluminium. Fatigue endurance limit of composites may approach 60% of their ultimate tensile strength. For steel and aluminium, this value is considerably lower. Composite parts can eliminate joints/fasteners, providing part simplification and integrated design compared to conventional metallic parts. Composites exhibit excellent corrosion resistance and fire retardancy. Composites are more versatile than metals and can be tailored to meet performance needs and complex design requirements. In view of these all advantages in use of the composite materials. In the present paper, an effort is made to endure the material behaviour with the different cross-sections of the stiffeners to find out the best capable cross-section with respect to the material will be drawn with the results in the further sections.

1.4 Advantages of ANSYS Workbench Software

ANSYS Workbench is a part of the Workflow Technology which can be treated as an Engineering Simulation platform. Compared with the other simulation softwares, it has the most desirable characteristics in the performance.

- ANSYS Workbench comes with the bi-directional CAD connectivity.
- An automated project level updates mechanism.
- It has a pervasive parameter management.
- Integrated Optimization tools.
- User friendly environment which helps to deliver the increased productivity undertaking FEA & CFD.

In the present paper, Structural analysis of simulation is used to evaluate the problem at one platform where it made possible to bring the modeling, meshing, solver and analysis together. Here a Static Structural analysis is performed with the major tools are:

- ANSYS DesignModeler
- ANSYS Meshing
- ANSYS Mechanical Solver

Static Structural (ANSYS) is the basic interface to start the problem in the workbench. It includes all the above mentioned tools in a sequence and has its own working methodology with the ease of data in each step of solution.

2. Comparison of Stiffener Cross-section with Confining Material

An attempt is made to compare the performance of the stiffener cross-sections versus material. Three different Cross- Sections are considered for the three different type of materials drawing the results of Stresses and Deformation in each set. This comparison can be used to highlight the different advantages and disadvantages of the different section shapes and confining materials.

Designers face many decisions when laying out the details of a section. For each specific application, a slightly different performance standard may be found. By understanding the effects of these two design variables, the designer is able to choose the shape or confining material or both that exhibit more optimal performance for the specific application. In further sections the properties of the each material is presented along with the cross-sections.

2.1 Materials and Properties Considered for the analysis:

Materials considered to perform the analysis are:
1) Structural Steel
2) Aluminum Alloy
3) Carbon Epoxy 230GPa_UD_Prepeg

2.2. Cross – Sections Considered:

Cross-sections considered to evaluate the structural strength of the panel are:
1) C – Section (Channel – Section)
2) Hat – Section
3) I – Section

Further evaluation of the behavior of the stiffened panel sub-divided into three categories with respective sections compared with the three materials.

3. Problem Analysis

3.1 Problem Definition

To evaluate the structural strength of the stiffened panel with the varied Cross-sections under in-plane loading in comparison with different material characteristics.

Where to find out the most feasible section for the design of stiffened panel with respect to the materials and their environmental conditions in use.

3.2 Analysis

A stiffened plate with a single stiffener type attached parallel to *y*-axis along with the notations for significant dimensions and coordinate system used for the present analysis . It is assumed that the stiffeners are always parallel to the edges of the plate and they are rigidly connected to the plate.
The analysis is further based on the following assumptions:
- Plate and stiffener materials are considered to be a single material, isotropic, and linearly elastic.
- Thicknesses of the plate and stiffener are uniform.
- The thickness of the plate is sufficiently small compared to the lateral dimensions, so that the effect of shear deformation and rotary inertia may be neglected.

Present thesis deals with the behavior of the stiffened panels subjected to in-plane loading with the different cross-sections compared with the different kind of materials to evaluate the structural strength of the stiffened panels in the aircraft construction. As a part of the thesis, three different materials used which have its own material properties (Discussed in the later sections) to perform the structural strength analysis with the three different Cross-sections.

To investigate the structural strength of the stiffened panel subjected to the in-plane loading, a rectangular stiffened panel of dimensions 100*100mm with the thickness of 1mm, stiffened in both longitudinal and transversely is taken on which the load of 10KPa is applied in longitudinal direction. Stress (Von-misses Stress) and deformation are derived in the analysis process to determine the better feasible Cross-section with the better use of material in the design of stiffened panels.

4. Results

The objective of the present study is to investigate the effect of large deflection on the static behaviour of stiffened panels and also to determine the influence of different stiffener cross-sections. The present analysis is carried out for uni-axially single stiffened panel, where y-direction stiffeners are present along the center line of the stiffened panel.

In the present work, three different types of stiffener cross-section, namely, C - Section, Hat and I sections, are taken into account. In all the cases an in-plane loading has been considered. In comparison with the cross-sections three different types materials namely Structural Steel, Aluminium and a composite material Carbon Epoxy_230GPa_UD_Prepreg are taken into account for the analysis. For the further analysis, panel has been stiffened both longitudinally and transversely in order to avoid the effects of shear deformation and rotary inertia.

4.1 Validation Study

The results of the present analysis are validated through comparison with previously published and established results. Analysis has been made to observe the Deformation and Equivalent Stress varying for the three Sections namely: C – Section, Hat – Section, and I – Section respective to the three materials. The resultant deformation and Stresses are shown in the figures:

4.2 Evaluation of Stiffened panel with the stiffener C – Section

The effect of deformation and the von-misses stress under applied conditions of the Stiffened panel attached with stiffener Channel cross-sections (C-Section) for the three different materials are given in the below sections.

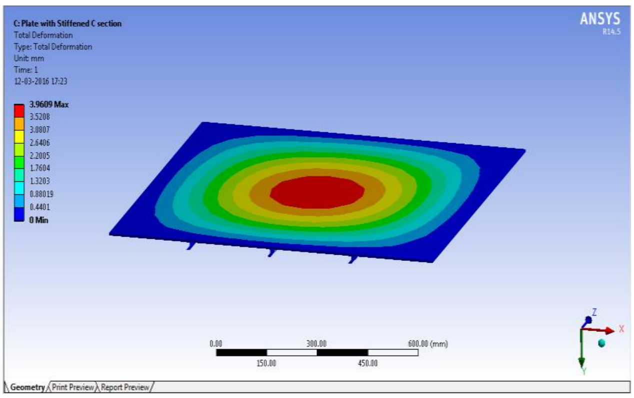

Figure 4.1: Deformation of the C-section for the material Structural Steel

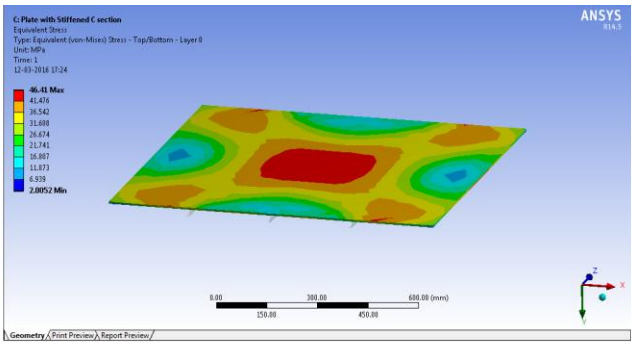

Figure 4.2: Equivalent Stress (Von-misses Stress) of the C-section for the material Structural Steel

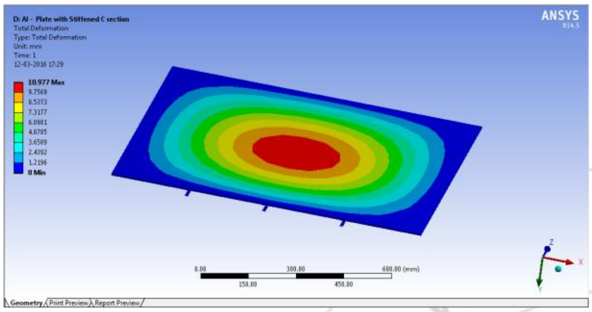

Figure 4.3: Deformation of the C-section for the material Aluminium Alloy

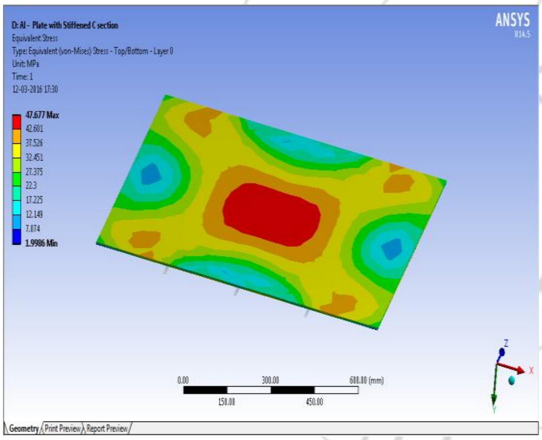

Figure 4.4: Equivalent Stress (Von-misses Stress) of the C-section for the material Aluminium Alloy

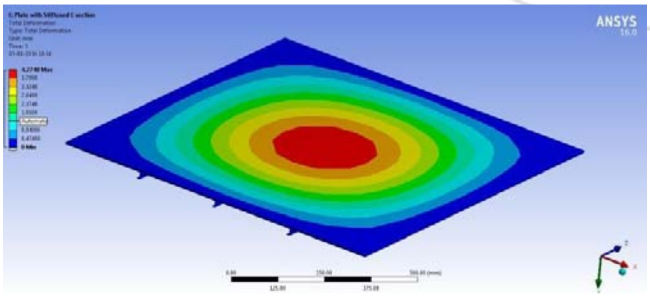

Figure 4.5: Deformation of the C-section for the material Carbon Epoxy 230GPa_UD_Prepeg

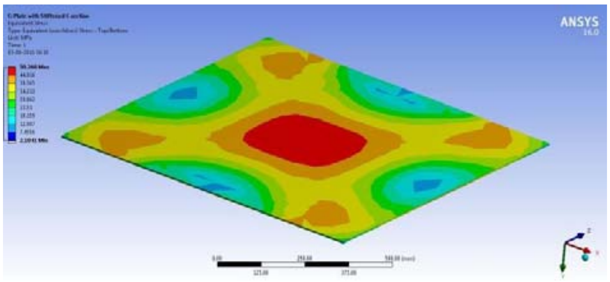

Figure 4.6: Equivalent Stress (Von-misses Stress) of the C-section for the material Carbon Epoxy 230GPa_UD_Prepeg

4.3 Evaluation of Stiffened panel with the stiffener Hat – Section

The effect of deformation and the von-misses stress under applied conditions of the Stiffened panel attached with stiffener Hat cross-sections (Hat-Section) for the three different materials are given in the below sections.

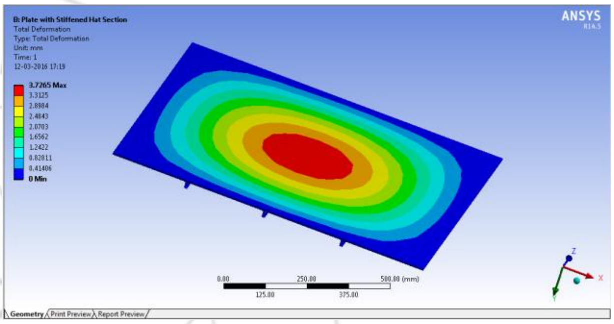

Figure 4.7: Deformation of the Hat-section for the material Structural Steel

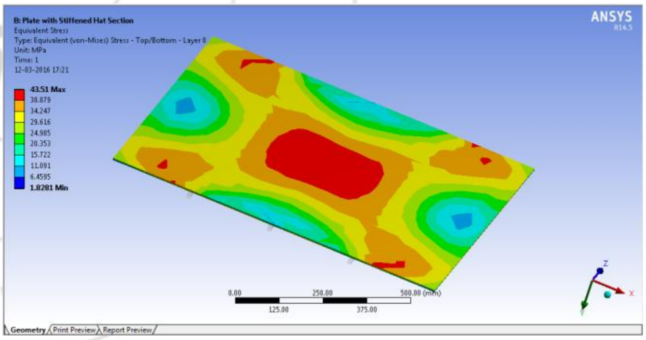

Figure 4.8: Equivalent Stress (Von-misses Stress) of the Hat-section for the material Structural Steel

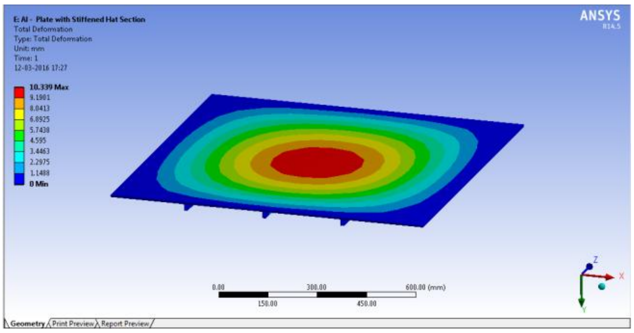

Figure 4.9: Deformation of the Hat-section for the material Aluminium Alloy

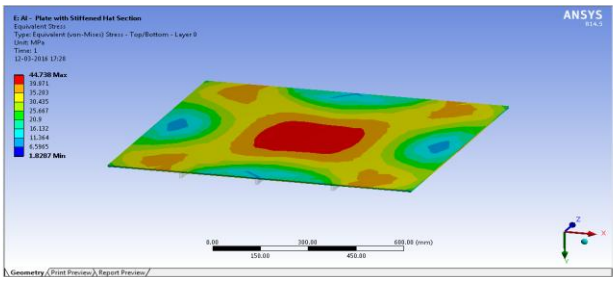

Figure 4.10: Equivalent Stress (Von-misses Stress) of the Hat-section for the material Aluminium Alloy

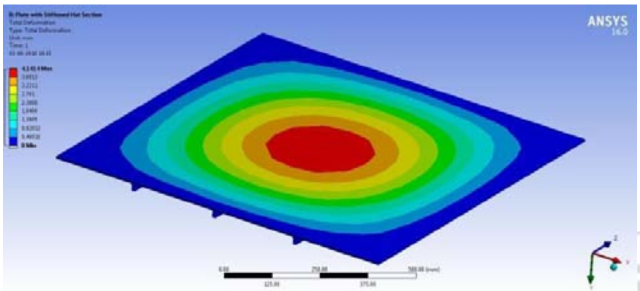

Figure 4.11: Deformation of the Hat-section for the material Carbon Epoxy 230GPa_UD_Prepreg

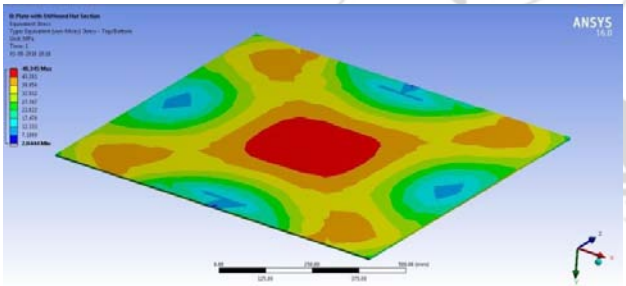

Figure 4.12: Equivalent Stress (Von-misses Stress) of the Hat-section for the material Carbon Epoxy 230GPa_UD_Prepreg

4.4 Evaluation of Stiffened panel with the stiffener I – Section

The effect of deformation and the von-misses stress under applied conditions of the Stiffened panel attached with stiffener "I" cross-sections (I-Section) for the three different materials are given in the below sections.

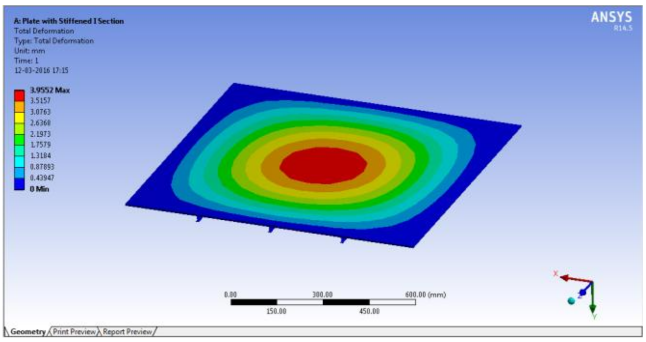

Figure 4.13: Deformation of the I-section for the material Structural Steel

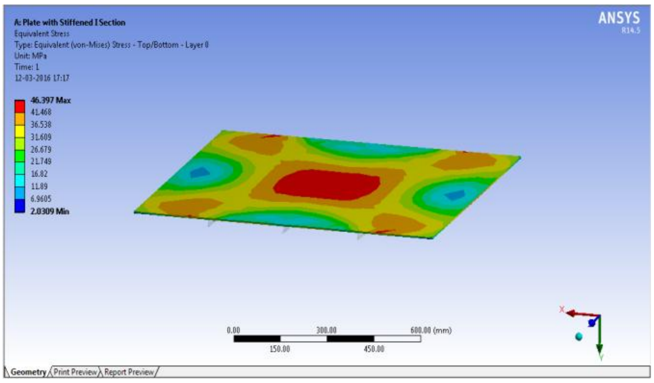

Figure 4.14: Equivalent Stress (Von-misses Stress) of the I-section for the material Structural Steel

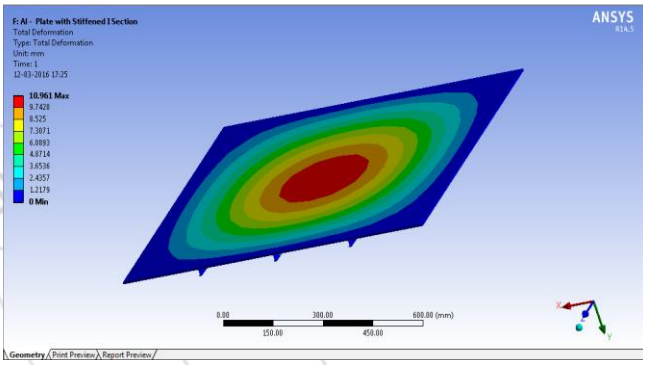

Figure 4.15: Deformation of the I-section for the material Aluminium Alloy

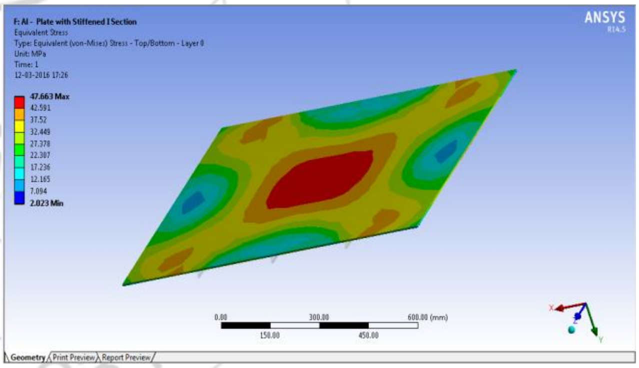

Figure 4.16: Equivalent Stress (Von-misses Stress) of the I-section for the material Aluminium Alloy

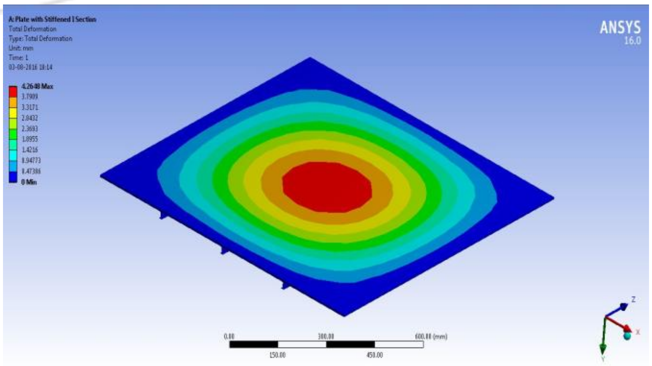

Figure 4.17: Deformation of the I-section for the material Carbon Epoxy 230GPa_UD_Prepreg

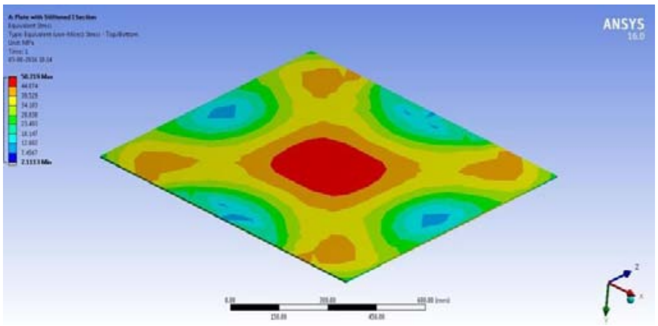

Figure 4.18: Equivalent Stress (Von-misses Stress) of the I-section for the material Carbon Epoxy 230GPa_UD_Prepreg

Table 1: Tabular form of the results derived

	Deformation			Equivalent Stress (Von- Misses Stress)		
	C - Section	Hat-Section	I – Section	C - Section	Hat-Section	I – Section
Structural Steel	3.96mm	3.72mm	3.95mm	46.41MPa	43.51MPa	46.39MPa
Aluminium Alloy	10.97mm	10.33mm	10.96mm	47.67Mpa	44.73Mpa	47.66Mpa
Carbon Epoxy_230GPa	4.27mm	4.14mm	4.26mm	50.26MPa	48.34MPa	50.21Mpa

5. Conclusion

Generally, the material that is used in the construction of aircraft is aluminum. But now the bigger aircraft companies like Boeing Airbus have already started using composite material also for their aircraft. So we tried to compare the two materials along with the other material which is used in aerospace industry with the minimal in the present industry i.e. Structural Steel, Aluminium and Composite material Carbon Epoxy_230GPa_UD_Prepreg through ANSYS Workbench, found out the results that which material can withstand the loads applied and have less deformation. In the present study a Uni-directional (UD) composite material has been choosen.

So the comparision is made purely analytical. Based on the study made, the following conclusions are drawn:

- Static structural analysis using the software ANSYS Workbench is capable to predict the the better section in considering the sectional behaviors subjected to the in-plane loading with respect to the change of material and its properties.
- Upon the applied load Hat – Section is drawn to be the feasible section than compared to the other two sections C – Section and I – Section.
- Steel and Composite material Carbon Epoxy shown the near results of deformation. Where the steel results are varied.
- Aluminium gets deformed easily with some amount of loads where Carbon Epoxy shown the less deformation with the same amount of loads.
- Physical strength, toughness and light weight are the features of Carbon epoxy material. Carbon Epoxy also has good vibration damping, chemical conductivity compared to aluminium.
- The observed behaviour of the Carbon Epoxy is drawn to be desirable with the Hat-Section than compared to the other two Sections of the stiffeners.
- The properties of composite material Carbon Epoxy, such as high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion, make them very popular in aerospace.
- Aluminum has some disadvantages like they are Prone to corrosion, so need protective finishes, particularly magnesium alloys. Many alloys have limited strength, especially at elevated temperatures.
- The applications of the steel are limited due to its weight. Though steel can be up to four times stronger and three times stiffer than aluminum, it is also three times heavier. Aluminum is lighter than steel, because it is less dense. By using aluminum, the skin can be made thicker (to help reduce buckling and fatigue) without adding as much weight.

Finally, from the analysis we found that the steel and composite material Carbon Epoxy_230GPa_UD_Prepreg shown the better results for the Hat-Section than compared to the alluminium. But due to the limitations of the steel applications in the aerospace industry, Carbon Epoxy is more robust than the aluminum material; also found that Hat-section gives less deformation than that of C-section and I-section.

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